# Dynamic Operation Strategy for Elastic Optical Networks

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***Abstract*—The need for high capacity and efficient optical networks is consistent. It is driven by the traffic volume and dynamicity requirements that are evolving as new applications and use cases emerge. At the same time, managing network costs is also important. We present a strategy for the efficient dynamic operation of elastic optical networks (EONs). It consists of a planning algorithm, a traffic predictor and a reconfiguration algorithm to handle dynamic events. Significant spectrum savings are observed.**

***Keywords*—Optical networks, Dynamic network operation**

## I. Introduction

Optical networks are crucial for communications and the ultimate internet traffic carrier. The advent of new applications, such as high definition video and game streaming, cloud computing and 5G networks, result in unprecedented requirements for network dynamicity and uninterrupted operation. The network operator should be able to plan, orchestrate and manage the network's resources to satisfy both expected (e.g. periodic) and unexpected (dynamic) demands, while reducing costs through efficient operation.

In this paper we propose a strategy for the efficient dynamic operation of EONs. It consists of: i) a planning algorithm that takes into account daily periodic traffic variations, ii) a short term (intraday) traffic predictor, iii) a heuristic reconfiguration algorithm that leverages the output of the traffic predictor to optimize the network in real time, coping with dynamic and unexpected situations. The planning algorithm makes spectrum allocation decisions for different time periods based on the periodic traffic demands. In doing so, it leverages spectrum sharing among appropriate demands. During the day, a traffic predictor closely monitors the traffic demands. If it predicts a traffic volume increase that cannot be served by the planned capacity, the heuristic algorithm takes dynamic reconfiguration actions to ensure that the network continues serving the increased projected demands without interruption.

The novelty of our proposal lies in the joint operation of a planning and a heuristic reconfiguration algorithm. Both are designed to work seamlessly together. This results in significant spectrum savings as indicated in our experiments.

## II. Outline Of Strategy

Internet traffic volume is known to vary according a day-night trend. It is desirable and possible for the rate of different connections to be negatively correlated in time (e.g., by programming datacenter backups during the night, when residential traffic is reduced). Then the spectrum of the negatively correlated connections can be shared. Previous works have researched variations of this problem [1]. Our Integer Linear Programming (ILP) planning algorithm is designed to allow hitless (without traffic interruption) reconfiguration of the network and also to work seamlessly with a heuristic reconfiguration algorithm. The ILP algorithm aims to route the negatively correlated lightpaths next to each other in terms of spectrum. By doing so, a certain portion of the spectrum can be utilized by different lightpaths during two separate time periods (e.g. day or night). Since the lightpaths that share resources are spectrum-adjacent, the spectrum sharing can be performed without traffic interruption [2].

The planning algorithm is designed to serve the *expected* daily periodic traffic demands in an efficient manner by exploiting spectrum sharing. However, certain events (e.g. athletic) occurring during the day may cause significant (unexpected) traffic spikes [3]. One approach to cope with these traffic spikes is overprovisioning. This is however inefficient and results in unnecessary resource consumption.

We propose to leverage a traffic predictor to anticipate such traffic spikes, and a heuristic algorithm to dynamically re-

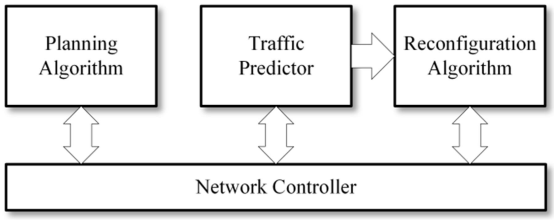


Fig. 1 The basic elements of the proposed strategy.

optimize the network *if and when* needed, based on the projected demands. The heuristic algorithm tries to serve a spike by changing some attributes of certain lightpaths or by establishing a new lightpath. After the traffic spike has faded, the network will return to its normal (planned) configuration. We assume that the planned time period reconfigurations will occur in after-hours where no spikes are typically observed. Therefore, all reconfiguration changes that the heuristic algorithm may have done to cope with a traffic spike, will be reversed before the planned time period changes, and no configuration conflicts will occur. In any case, a new lightpath can be established to handle certain situations.

## III. Planning Algorithm

In this section we present the ILP planning algorithm designed to account for the periodic traffic variations that occur during e.g., the day and night. The objective of the algorithm is to minimize the occupied spectrum. We assume that each demand is routed over its shortest path. For a connection c, based on the required rate, we find the feasible (according to a QTool such as [4]) transmission tuples

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(combination of modulation format and baud rate) whose rate can satisfy the demand. We select the tuple with the higher modulation format (thus the smaller baudrate/fewer spectrum slots). If no feasible tuple is available, we place regenerators.

**Inputs:**

- $C$: Set of all connections,
- $L$: Set of links of the network,
- $F$: Total number of spectrum slots,
- $Z^t_c$: Required number of slots for connection $c$ at time period $t$=1,2.

**Variables:**

- $u^t_{cfs}$: Boolean variable equal to 1 if connection $c$ uses slots ($f$, $f$+$s$-1) at time period $t$=1,2 where $s=Z^t_c$,
- $y^t$: Integer variable($\leq F$) that denotes the maximum spectrum slot number used in time period $t$=1,2.

**Objective:** $\min\left(y^1 + y^2\right)$, subject to:

- Connection serving constraints for time period $t$=1,2:

$$\forall c \in C, s = Z^t_c : \sum_{f | f+s-1 \leq F} u^t_{cfs} = 1 \tag{1}$$

$$\forall c \in C : \sum_{s \neq Z^t_c} \sum_{f | f+s-1 \leq F} u^t_{cfs} = 0 \tag{2}$$

- Non overlapping slot assignment constraints for time period $t$=1,2:

$$\forall\, l \in L, \forall i \in [1, F]: \sum_{c \in C | l \in c, s = Z^t_c} \sum_{f | f \leq i \text{ and } f+s-1 \geq i} u^t_{cfs} \leq 1 \tag{3}$$

- Maximum slot used constraints for time period $t$=1,2:

$$\forall l \in L, \forall f \in [1, F]: \sum_{c \in C | l \in c, s = Z^t_c, f+s-1 \leq F} (f+s-1) u^t_{cfs} \leq y^t \tag{4}$$

- Connection ordering constraints for time periods $t$=1,2:

$$\begin{array}{ll} \forall c \in C, s = Z^1_c, s' = Z^2_c, & \\ \forall f \in [1, F] \,|\, f+s-1 \leq F, & : u^1_{cfs} = u^2_{cf's'} \\ \forall f' \in [f-2, f+2] \,|\, f'+s'-1 \leq F & \end{array} \tag{5}$$

Constraint (1) defines the spectrum of a connection $c$, in terms of the starting frequency $f$ and the respective spectrum slots $s$=$Z_c$. Constraint (4) defines the maximum slot used for *every possible* starting slot $f$. The value $f+s-1$ is equal to the ending slot of a connection that requires $s$ slots. Constraint (5) limits the spectrum reconfiguration of the connections from one time period to another to at most 2 slots of 12.5 GHz. Therefore the spectrum ordering of the connections remains unchanged assuming the minimum number of slots of a connection is 3. As a result the push-pull technique [2] can be used to change the frequency of the connections without traffic interruption. Also, the number of reconfiguration actions is maintained low.

The formulation can be solved relatively quickly for realistic scenarios as shown in the simulations. If the ILP cannot provide a good solution in a given timeframe, we can order the demands and use a heuristic to serve them one-by-one. A meta-heuristic can search other orderings for better solutions.

## IV. Dynamic Network Operation

In this section we present the algorithms that are responsible for the network reconfiguration when a traffic spike occurs.

### *A. Traffic Predictor*

A number of previous works [5] focus on traffic prediction. The idea is to use previous observed (measured) data of IP traffic rates between nodes, in order to predict future demands. Typically, a traffic predictor based on e.g. neural networks is trained for each origin-destination (OD) pair of IP nodes. There are many different timeframes for the prediction (e.g. minutes or days), depending on the purpose of the prediction. For short term prediction, Convolutional Neural Networks (CNNs) have been applied to predict the short term electricity load [6]. In our case the input to the CNN can be the traffic volume of a number (e.g. 5) of previous time steps and the output is the predicted traffic volume for a number of future time steps (e.g. 1-3). A basic appropriate CNN architecture consists of a convolutional hidden layer and a pooling layer. Then a flatten layer is used to feed the subsequent dense fully connected layer that provides the output. The prediction is given to the heuristic algorithm responsible for the reconfiguration of the network.

### *B. Heuristic Reconfiguration Algorithm*

The heuristic reconfiguration algorithm takes as input the current network state (i.e. set of established lightpaths, their attributes: baud rate, etc.), and the predicted maximum rate for each OD pair over a period. If the predicted maximum rate cannot be served by the established lightpaths, the algorithm must find a way to increase the net rate of the appropriate lightpaths so as to accommodate the unserved traffic. In doing so it tries different transmission configurations and it leverages a QTool [4] to estimate whether the resulting QoT will be acceptable. A first step is to increase the modulation format since this solution does not require additional configuration changes (to allocate more spectrum). The most efficient modulation format may not always be used due to margin or other policies. However a short-term format change to a more efficient could be tolerable. If the QoT of a higher format is not acceptable then the algorithm investigates the baud rate increase of the appropriate lightpaths. The increased baud rate requires additional spectrum slots that can be acquired e.g. according to [7]. The modulation format, baud rate and spectrum reconfigurations can all be executed hitlessly [7], [8]. The baud rate increase may not be feasible for a number of reasons: for example it may result in an undesirable cascade of lightpaths shifts, or an unacceptable QoT of a lightpath or the capacity demands cannot be satisfied by the baud rate increase. If so, a new lightpath is established using a separate transponder to serve the additional required capacity, without changing the configuration of existing lightpaths. When the traffic spike diminishes, the previous configuration is restored.

## V. Results

We evaluated our proposed strategy through simulation experiments. We first estimated the accuracy of the short term traffic predictor. We assumed the CNN architecture defined in section IV.A. The convolutional layer had 64 filters and kernel size of 2. We assumed 5 time steps as inputs that are used to predict 5 future time steps. Each time step could correspond to the aggregated IP traffic of e.g. 5 or 15 minutes. We produced the training and test data as described in [9]: we summed 4 different sin time series and added Gaussian noise with zero mean and standard deviation of 0.05. We produced 150 traffic instances and averaged the results. The CNN predicted the first three time steps with Root Relative Squared Error (RRSE) of approximately 0.07, while the fourth and fifth time step had RRSE of 0.1 and 0.11 respectively.

Next we evaluated the benefits of the planning algorithm. We assumed the DT topology (12 nodes, 40 bidirectional links) and an Italian backbone topology (27 nodes, 43 bidirectional links) and random traffic with the demands' sources and destinations uniformly distributed over all nodes. We consider a total of 130 lightpaths that are served in two traffic scenarios. The first (ScenA) consists of 200G (PM-16QAM, 28Gbaud, 37.5GHz bandwidth) and 400G (PM-16QAM, 56Gbaud, 75GHz bandwidth) lightpaths (80% and 20% respectively of all the lightpaths, randomly decided). We assume that from one time period to the other a random 12.5% of the 200G lightpaths will change to 400G, and 50% of 400G will change to 200G. The second traffic scenario (ScenB) consists of 200G and 400G connections: 60% and 40% respectively. From one time period to the other a random 50% of the 200G lightpaths will change to 400G and 50% of the 400G will change to 200G. We created 150 random traffic instances and averaged the results. The simulations where carried out using MATLAB, CPLEX and a Quad-core CPU at 4 GHz. The running time of the ILP was 40 minutes. We compared our approach to planning without considering spectrum sharing: we initially plan the network assuming only the demands of the first time period. Then in the second period, the lightpaths whose rate is downgraded contract their spectrum. Lightpaths whose rate is increased can expand their spectrum if there happens to be free spectrum. If there isn't, then a push-pull algorithm is used to create the necessary spectrum. The comparison metric is the spectrum utilization (defined as the *maximum* spectrum utilization among all links). In Table 1 we notice that in the DT topology the ILP requires on average 6.8% and 21.6% less spectrum in ScenA and ScenB respectively. The reason for the big difference between the spectrum savings of the two scenarios is the small amount of connections that change their rate in ScenA when compared to ScenB. However, even in the circumstances of ScenA, the ILP still manages to offer spectrum utilization savings. Note that the DT topology has a bit larger savings than the Italian. This can be attributed to the fewer nodes and links that provide more spectrum sharing opportunities (given the same amount of lightpaths).

Next we evaluated the heuristic reconfiguration algorithm assuming that the traffic spike caused by an important event would require a 30% increase in some lightpaths' rate. The usual practice that network operators follow is overprovisioning. In this case the network operator does not know which lightpaths might be affected by a number of different possible spikes, and therefore all lightpaths' rate are overprovisioned by 30% at all times. The proposed heuristic adjusts the rate of only the required lightpaths and the changes are reversed after the spike diminishes. In all scenarios the rate increase was carried out by increasing the baud rate, requiring 1 extra spectrum slot. The comparison metric is again the spectrum utilization. An alternative to overprovisioning could be to establish an appropriate set of new lightpaths whenever a spike is predicted. However this scenario would require several spare transponders dedicated at *each* node. When compared to this case, the benefits of our strategy would mainly be equipment related. The exact benefits are a topic of future work. In Table 1 we notice the usage of the heuristic algorithm requires on average approximately 19% less spectrum. The *percentage* savings are similar in all cases since we compare to overprovisioning of the rate of all the lightpaths by the same percent.

When both the planning and the reconfiguration algorithm are used together, they require at least 24.8% and at most 40.4 less spectrum than the respective alternatives combined. This demonstrates the advantage of the joint operation of both the planning and the reconfiguration algorithm.

Table 1: Percentage spectrum utilization savings of our strategy compared to the alternatives.

| | DT topology | | Italian topology | |
|---|---|---|---|---|
| | ScenA | ScenB | ScenA | ScenB |
| ILP | 6.8 | 21.6 | 5.2 | 20.3 |
| Heuristic | 19.1 | 19 | 19.3 | 19.1 |
| ILP+Heuristic | 25.7 | 40.4 | 24.8 | 39.5 |

## VI. CONCLUSION

We proposed a novel strategy for the dynamic operation of optical networks. Significant spectrum savings can be achieved through the combination of a planning algorithm that accounts for expected traffic volume variations over different daily time periods, and a traffic predictor and reconfiguration algorithm to deal with unplanned fluctuations.

## ACKNOWLEDGMENT

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## REFERENCES

[1] I. Tomkos, et al, "A tutorial on the flexible optical networking paradigm: State of the art, trends, and research challenges," in *Proceedings of the IEEE*, vol.102, no. 9, pp. 1317-1337, Sept. 2014.
[2] F. Cugini, et al. "Push-Pull Defragmentation Without Traffic Disruption in Flexible Grid Optical Networks," in *Journal of Lightwave Technology*, vol. 31, no. 1, pp. 125-133, Jan. 2013.
[3] "Conviva's 2018 Annual State of the Streaming TV Industry," https://www.conviva.com/research/convivas-2018-annual-state-streaming-tv-industry
[4] I. Sartzetakis, et al, "Accurate Quality of Transmission Estimation With Machine Learning," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 11, no. 3, pp. 140-150, Mar. 2019.
[5] F. Musumeci et al., "An Overview on Application of Machine Learning Techniques in Optical Networks," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1383-1408, Second quarter 2019.
[6] X. Dong,et al, "Short-term load forecasting in smart grid: A combined CNN and K-means clustering approach," *IEEE International Conference on Big Data and Smart Computing (BigComp)*, Jeju, 2017.
[7] I. Sartzetakis, et al, "Cross-Layer Adaptive Elastic Optical Networks," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 10, no. 2, pp. A154-A164, Feb. 2018.
[8] A. Dupas et al, "Ultra-fast Hitless 100Gbit/s Real-Time Bandwidth Variable Transmitter with SDN optical control," *Optical Fiber Communications Conference and Exposition (OFC)*, San Diego, CA, 2018.
[9] A. P. Vela, et al, "Traffic generation for telecom cloud-based simulation," *18th International Conference on Transparent Optical Networks (ICTON)*, Trento, 2016.